MISSOURI RIVER

SEDIMENT TRANSPORT RELATIONSHIPS

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I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

Relatively clear water has been released from the Gavins Point Dam (River Mile 811) since its closure in 1954. This flow may enlarge the river cross section, cause the lowering of the water surface and river bottom, impinge on the stability of the riverbanks, and affect the flow characteristics of the tributaries to the Missouri River in this particular reach.

A Missouri River degradation study between Yankton and Omaha was initiated in 1978 to evaluate degradation in the bed level and river stages through the use of the HEC-6 model. In order to make a quantitative assessment of the potential degradation, a reasonably reliable sediment transport relationship must be developed to predict the amount of sediment that a particular flow can carry. The purpose of this study is to develop a sediment transport relationship based on data collected from a comprehensive sediment and flow data collection program conducted at Yankton (River Mile 805.8), Sioux River (River Mile 752.3), Omaha (River Mile 615.9), and Nebraska City (River Mile 561.8). This sediment transport relationship can also be used to evaluate the sediment load balance at the Platte River - Missouri River confluence and other reaches.

All tables are in Appendix A.

B. REVIEW OF LITERATURE ON SEDIMENT TRANSPORT

Although a great deal of research has been conducted and many equations have been proposed on the variation of sediment transport rate with flow, there is not a generally accepted relationship available for large rivers. Following is a list of selected relationships; for a more complete list and descriptions of other transport equations, readers are referred to Graf (1971), Shen (1972), Vanoni (1975), and Raudkivi (1976).

1. DuBoy's Formula

$$q_s = k'\tau_o\,(\tau_o - \tau_c) \tag{1}$$

where q_s is the sediment transport rate in pounds per second per foot of width (lbs/s/ft), k' is a coefficient with dimensions of $ft^3/lb/s$, and τ_o and τ_c are, respectively, the shear stress in lb/ft^2 for a particular flow condition and for the incipient motion.

2. Einstein's Method

H. A. Einstein (1950) developed the most comprehensive sediment transport relationship available. His relationship is rather involved and includes several correction factors for such situations as the hiding of small sediment particles by large particles and the hiding of sediment particles in the viscous sublayer. He also presented a graphical relationship based on both field and laboratory data between

$$\phi\,(q_b) = \psi\,\left(\frac{\gamma_s - \gamma_f}{\gamma_f} \cdot \frac{D}{RS}\right) \tag{2}$$

where γ_s and γ_f are the specific weights of solids and fluids, respectively; D is the sediment particle size; R is the hydraulic radius; and S is the energy slope. Einstein then proceeded to use theoretically-derived relationships with certain assumptions to integrate the bed load and obtain the total load. His bed load function is reasonably sound theoretically, although his total load was not verified by data. Shen (1975) analyzed Einstein's bed load function based on more recent knowledge, and pointed out some deficiencies.

3. Colby's Relationship

Based on total sediment transport rates measured in various small rivers and during laboratory flow studies, Colby (1964) developed a series of graphs to define total sediment load (q_T) as a function of average flow velocity (V), water depth (d), sediment size (D), amount of fine sediment concentration (C) and water temperature (T). This can be represented by:

$$q_T = f\ (V, D, d, T, C) \tag{3}$$

Most of Colby's data were collected at flow depths of less than 2 feet. As his curves indicate, most of his sediment transport rates for flow depths of 10 to 100 feet were extrapolated.

4. Toffaleti's Relationship

Based on extensive data from seven rivers and laboartory flume data from several investigations, Toffaleti (1969) developed a total sediment transport relationship rather similar to that suggested by Einstein. The rivers he used were the Mississippi at St. Louis, the Rio Grande at Bernalillo, the Middle Loup, the Niobrara, and three rivers in the lower Mississippi basin. His vertical flow velocity distribution is expressed as

$$\frac{u}{V} = n_1\ \left(\frac{y}{d}\right)^{n_2} \tag{4}$$

where u is the flow velocity at a distance y from the river bed, V is the average flow velocity, n_1 is a coefficient, and n_2 is a function of flow temperature in the form

$$n_2 = 0.1198 + 0.00048\ T \tag{5}$$

where T is the water temperature in degrees Fahrenheit.

The sediment concentration in the flow is divided into four vertical zones, and the bed load discharge is assumed to take place in the lowest zone, or "bed zone." The lower limit of this bed zone is $y = 0$ and its upper limit is set at two sediment diameters. In the other three zones, the suspended sediment concentration C was found to vary with y as follows:

$$C_i = C_{ij} \left(\frac{y}{d}\right)^{-k_{ij} Z_i} \tag{6}$$

where i represents each sediment particle size, j indicates the particular zone, and k_{ij} and Z_j are constants. Toffaleti also developed a relationship to express suspended sediment transport rate in the lower zone as a function of flow velocity, sediment particle size, shear velocity and water temperature.

Since Toffaleti's equation was based on a great deal of data collected from large rivers, it has often been applied to obtain sediment transport rates for large rivers.

5. <u>Shen and Hung (1971) Regression Curve</u>

An empirical relationship between the sediment bed material load concentration and the flow condition was developed by Shen and Hung. They found that

$$C = f\left(\frac{V\ S^{0.57}}{w^{0.32}}\right) \tag{7}$$

where C is the total bed material load, V is the flow velocity in feet per second, S is the energy slope, and w is the fall velocity of the median sediment size of the sediment bed load material sample in feet per second. The relationship was derived based on data collected from laboratory flumes and from the Niobrara and Middle Loup Rivers.

Their curve was not verified by field data collected from large rivers because of the lack of knowledge of the division of sediment sizes between the wash load and the bed material load.

6. Yang's (1973) Expression

Yang believed that the unit stream power (a product of average flow velocity and energy slope) is a dominant factor in describing sediment transport rate. Through regression analysis he found that

$$C = f\left(\frac{wD}{\nu}, \frac{u_*}{w}, \frac{VS}{w} - \frac{V_c S}{w}\right) \tag{8}$$

where ν is the kinematic viscosity of flow, u_* is the shear velocity, V_c is the incipient flow velocity, w is the fall velocity of sediment particles, V is the average flow velocity, and S is the energy slope. All other terms were defined earlier.

Yang (1977) found that this equation and the relationship developed by Shen and Hung (1971) were better than many other equations.

C. GENERAL DISCUSSION

Most research on sediment transport rates has been conducted in relatively small laboratory flumes, and it is difficult to extrapolate such results to large rivers. On the other hand, many agencies have collected a great deal of field data from numerous rivers, but unfortunately, due to limited time and funds, insufficient comprehensive sediment data have been collected accurately in any single river to allow a reasonable analysis. The general practice is to plot the measured sediment transport rates versus flow discharge on a log-log graph, draw a curved line approximately through the middle of these widely-scattered data points, and use this curve for design purposes. For a given discharge, some data points might deviate by more than 100% from the value indicated by the curve.

An additional difficulty is the lack of reliable field data in a zone close to the river bed, as it is generally agreed that bed load cannot be accurately measured by a bed load sampler in large rivers with pronounced bed forms, and a suspended sampler cannot measure closer than 0.3 to 3 feet from the bed surface without disturbing the bed. The value of the ratio of the measured suspended sediment load to the total transport load is being actively debated. If one estimates the vertical flow distribution and the suspended sediment concentration in the unmeasured zone and uses that information to estimate the sediment load in the unmeasured zone, he will frequently find that the measured load can be 10% to 120% of the total load. This ratio is a function of flow and sediment characteristics, and if it is not known, one does not know the true sediment transport rate of a river and thus cannot determine the accuracy of a transport equation.

In view of these difficulties, a carefully designed data collection program has been carried out at several stations on the Missouri River. The cross sections at each gaging station were divided into several verticals and flow velocities as well as point suspended sediment samples were normally measured at six points in each vertical. It is hoped that these vertical flow distributions and vertical suspended sediment transport rates can be established and extended to the river bed to determine the total sediment transport rate.